

Tropical Moored Buoy Arrays: PIRATA, RAMA, Flux Reference Sites, and Tropical Sea Surface Salinity

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1. PROJECT SUMMARY

This report describes FY 2008 progress in the implementation of the Tropical Moored Buoy Array program as a NOAA contribution to development of the Global Ocean Observing System (GOOS), the Global Climate Observing System (GCOS), and the Global Earth Observing System of Systems (GEOSS). The goal of the moored buoy program is to provide high quality moored time series and related data throughout the global tropics for improved description, understanding and prediction of seasonal to decadal time scale climate variability. Focus on the tropics is dictated by its role as a heat engine for the Earth's climate system, engendering phenomena such as the El Niño/Southern Oscillation (ENSO), the monsoons, the Indian Ocean Dipole, and tropical Atlantic climate variability. This program supports NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." It also provides key observational underpinning for the international Climate Variability and Predictability (CLIVAR) program's research efforts on climate variability and change. Management of the tropical moored buoy array program is consistent with the "Ten Climate Monitoring Principles". Program oversight at the international level is through the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A new web site containing comprehensive information on the program can be found at <http://www.pmel.noaa.gov/tao/global/global.html>.

Four major elements to the Tropical Moored Buoy Array program are described below. These are the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA), the Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA), Flux Reference Stations, and Tropical Pacific Salinity. Discussion of these elements is followed by comments about fishing vandalism, point current meter measurements, a summary of community service, and a list of FY 2008 publications supported by this research. Chris Meinig of PMEL will submit a separate progress report on Engineering Development, a fifth element of the Tropical Moored Buoy Array program. The TAO array, also part of the Tropical Moored Buoy Array program, is managed by NOAA/NDBC.

2. ACCOMPLISHMENTS

2.1. PIRATA

As of September 30, 2008 the PIRATA Array consists of 17 ATLAS moorings

and one subsurface ADCP. This includes the 10 ATLAS mooring PIRATA core array configuration (as agreed upon for the 2001-2006 consolidation phase of the program), three ‘Southwest (SW) Extension’ moorings, and 4 ‘Northeast (NE) Extension’ moorings. The SW Extension moorings were first deployed in August 2005 and initial capitalization costs were supported by INPE in Brazil. NOAA has since assumed responsibility for ongoing equipment replacement and refurbishment. Two NE Extension moorings were deployed in June 2006 and two additional sites deployed in May 2007. A ‘Southeast (SE) Extension’ mooring sponsored by the University of Capetown, South Africa, was deployed in June 2006 and recovered in June 2007, but not redeployed. This site may be reoccupied if sustained funding becomes available.

PMEL is charged with providing equipment and technical support for ATLAS moorings and instrumentation, and support for data processing, dissemination, and display. France provides equipment and processing for the subsurface ADCP site. France and Brazil provide ship time and support for equipment shipments and also provide technician support at sea. NOAA provided ship time in FY 2006 and FY 2007 to support the Northeast Extension and the core mooring at 0°, 23° W. NOAA ship time was planned for FY 2008, but mechanical problems and other issues with the NOAA Ship Ron Brown resulted in a cancellation of a Northeast Extension cruise scheduled for April 2008. NOAA contracted the French RV Antea for this work in October 2008. PMEL and AOML are jointly staffing this cruise.

Eight (8) ATLAS moorings were recovered and 8 moorings (5 core array and 3 SW Extension) were deployed from the Brazilian R/V Antares in March-May 2008 (36 sea days, 25 PMEL person-days: PMEL staffed only 2 of 3 cruise legs). Four core array moorings were recovered and 5 deployed from the RV Antea in September 2008. One of the moorings was vandalized before the end of the cruise. A second mooring was deployed from spare equipment, but the damaged mooring was not recovered due to lack of time.

All PIRATA moorings measure wind speed and direction, air temperature, relative humidity, short wave radiation, precipitation, sea surface temperature and salinity, ocean temperatures at 10 depths down to 500 m and salinity at 3 depths down to 120 m. Three PIRATA sites have been enhanced as flux reference sites (see 2.3 below). The four NE Extension moorings have been enhanced with a near surface current measurement and one additional subsurface salinity measurement. One of the NE Extension moorings has been enhanced to the level of a flux site.

PIRATA data are available from the PIRATA web site (www.pmel.noaa.gov/pirata/) and the TAO web site (www.pmel.noaa.gov/tao/disdel/disdel.html). There is also a mirror sites in France. A mirror site in Brazil is no longer active. Collection, processing, and dissemination of shipboard CTD and ADCP data are the responsibility of France and Brazil, with AOML taking responsibility for these data collected during the Northeast Extension cruises. Northeast Extension cruise data, including quality controlled CTD, Thermosalinograph and XBT data, and accompanying cruise reports are available at the PIRATA Northeast

Extension web site (<http://www.aoml.noaa.gov/phod/pne>).

Real-time data return was 76% overall for FY 2008, 11% lower than for FY 2007, but within 1% of FY 2006. The lower value in FY 2008 was due to the loss of a mooring in the Gulf of Guinea and the delay in the Northeast Extension cruise. The sites with the lowest data return were 0°, 23° W (42% data return due to vandalism and cruise delay), 0°, 0° (58%, mooring lost) and the Northeast Extension moorings (57% to 70%, due to battery failure, vandalism and cruise delay).

Real-time PIRATA data return by variable for FY 2008 (and for comparison, FY 2007) is shown below. Three Flux Reference and one NE Extension sites are enhanced for current, longwave radiation (LWR) and barometric pressure (BP). The other NE Extension moorings also measure currents as well. Real time current velocity data return has been disappointingly low. In addition to vandalism and cruise delays affecting all data return, velocity data losses were higher due to problems with battery life and telemetry issues. Efforts to improve these measurements are in progress (Section 4).

	AIRT	SST	T(Z)	WIND	RH	Rain	SWR	LWR	SAL	BP	CUR	ALL
FY 2008	87	64	75	74	85	48	84	88	61	91	26	76
FY 2007	94	91	89	90	92	73	86	100	84	100	45	87

The TAO Project continues to update the content and functionality of its web site (<http://www.pmel.noaa.gov/tao/>). This site provides easy access to TAO/TRITON, PIRATA and Indian Ocean data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. For FY 2008, a total of 8706 separate user requests delivered 90,554 PIRATA data files, which represent 16% and 47% increases, respectively, from the year before.

PIRATA data are distributed via the GTS to centers such as NCEP, ECMWF, and Météo-France where they are used for operational weather, climate, and ocean forecasting and analyses. PIRATA data placed on the GTS include spot hourly values of wind speed and direction, air temperature, relative humidity, and sea surface temperature. Daily averaged subsurface temperature and salinity data are also transmitted on the GTS. Daily ftp transfers are made from PMEL to the CORIOLIS operational oceanography program in France. The MERCATOR program in France makes use of the CORIOLIS data base to generate operational ocean model based data assimilation products. PIRATA data are also available on the GODAE server in Monterey, California.

The PIRATA project was highlighted this year in a cover article in the *Bulletin of the American Meteorological Society* (Bourlès, Lumpkin, McPhaden *et al.*, Vol **89** (8), August 2008). This article provided an overview of PIRATA's history, scientific and logistical accomplishments, and future for the general scientific community. In this article, the acronym PIRATA was redefined as the Predication and Research Moored Array in the Tropical Atlantic.

2.2. Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA)

The CLIVAR/GOOS Indian Ocean Panel (IOP) developed an implementation plan for a multi-component ocean observing system, IndOOS. A key element of the system is a 46 element moored buoy array, the Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA). The first elements of the array were deployed by Japan in 2000-2001 by India in 2002. PMEL and India's National Institute of Oceanography (NIO) deployed the first ATLAS moorings in 2004.

In FY 2008 the number of PMEL sites in RAMA increased from 9 to 15, bringing the total number of sites deployed to 20, or 43% complete. Two of the new ATLAS sites was deployed on a PMEL/NIO cruise in November 2007 (15 sea days, 30 PMEL person days) from the Indian R/V Sagar Kanya. The other two new ATLAS sites were deployed in August 2007 from India's newest research vessel the Sagar Nidhi (28 sea days, 84 PMEL person days). Other operations from the Sagar Nidhi included the recovery of 2 ATLAS and 1 ADCP mooring and the deployment of 3 ATLAS and 10 ADCP moorings. In August 2008 PMEL deployed one ATLAS mooring in collaboration with France's *Laboratoire d'Océanographie - Expérimentation et Approches Numériques* (LOCEAN) from the RV Marion Dufresne (8 sea days, 8 PMEL person days). An ATLAS mooring scheduled for recovery at the site was left in place due to weather conditions. However, negotiations are underway to recover this mooring from the Sagar Kanya in November 2008. Four ATLAS moorings were recovered and new moorings deployed in September-October 2007 from the Baruna Jaya 3 (27 sea days, 54 PMEL person days).

PMEL has been actively engaged in developing partnerships to secure ship time necessary for implementing and maintaining RAMA. PMEL spearheaded efforts within NOAA to develop an MOU with the Ministry of Earth Science (MoES) in India for cooperative programs across a wide range of topics. The MOU was signed in April 2008. An Implementing Arrangement (IA) under this MOU for development of RAMA was signed in September 2008 in Delhi, India. As part of the IA, India has pledged a minimum of 60 days of ship time per year for 5 years. For the Baruna Jaya cruises, ship time was obtained via cooperative agreements between NOAA and Indonesia's Agency for the Assessment and Application of Technology (BPPT) and the Ministry for Marine Affairs and Fisheries (DKP). IAs between NOAA and each of the Indonesian agencies are under development and should be completed in 2009. Under these IAs, Indonesia will provide 30 sea days annually for dedicated RAMA implementation and maintenance. Additional sea days will be provided for joint RAMA/Indonesian GOOS (InaGOOS) mooring deployments at two designated RAMA sites. The most recent collaboration has been between PMEL and the Agulhas Somalia Current Large Marine Ecosystem (ASCLME) project. PMEL became aware of deployment opportunities on an ASCLME cruise through the IOP in mid 2008. As a result, two ATLAS moorings will be deployed in the southwest Indian Ocean (8°S and 12°S, 55°E) in November 2008.

All ATLAS moorings deployed in the Indian Ocean have the PIRATA suite of instrumentation, plus one additional water temperature measurement, 2 additional salinity

measurements and one near surface velocity measurement. One of the ATLAS moorings is enhanced for flux reference measurements (see 2.3 below).

RAMA real-time data return was 52% overall for FY 2008, substantially lower than in TAO or PIRATA. This was mainly due to higher rates of vandalism in the Indian Ocean basin (see 2.6 below) and mooring service intervals longer than the 1-year design lifetime of the moorings. Most service intervals for recent moorings have been 18 months (Table 1.)

Table 1. RAMA mooring service schedules.

Sites	Ship Nationality	Deployment	Recovery
1.5° N, 80.5° E 0° N, 80.5° E 1.5° S, 80.5° E	India	September 2006	August 2008
8° S, 67° E	France	January 2007	Not recovered yet. New mooring deployed August 2008
0° N, 90° E 1.5° N, 90° E 4° N, 90° E 8° N, 90° E	Indonesia	September –October 2007	Planned for April 2009
12° N, 90° E 15° N, 90° E	India	November 2007	October 2008

Of the 3 surface moorings deployed in September 2006, one was not found in August 2008 and the other 2 had no surface instrumentation attached. Both of the latter returned nearly complete subsurface data, thus percent data return for RAMA will increase when delay mode data are considered. Data return from the PMEL ADCP deployed at 0, 81°E was 100% for the second deployment in a row, resulting in a continuous record of nearly 4 years.

We note that RAMA (and PIRATA) winds are currently being used to verify Advanced SCATterometer (ASCAT) data (see map at: http://www.knmi.nl/scatterometer/ascat_osi_25_prod/ascat_app.cgi?cmd=buoy_validation&period=week&day=0&flag=no). The analysis is described in Bentamy, A., 2008: Characterization of ASCAT measurements based on buoy and QuikSCAT wind vector observations. Ocean Sci. Discuss., 5, 77–101. (available at <http://www.ocean-sci-discuss.net/5/77/2008/osd-5-77-2008.pdf>)

2.3. Flux Reference Stations

The OCEAN Sustained Interdisciplinary Timeseries Environment observation System (OceanSITES) is built around a worldwide network of long-term, deepwater reference stations measuring many oceanographic and meteorological variables of relevance to climate and biogeochemical cycles and is a contribution to the Global Ocean

Observing System and international research programs. PMEL is a major contributor to OceanSITES in the context of the Tropical Ocean Atmosphere (TAO) mooring array in the tropical Pacific, PIRATA and RAMA. Five equatorial Pacific moorings within the TAO/TRITON Array (4 ATLAS and 1 TRITON), three PIRATA moorings, and two (1 ATLAS and 1 TRITON) RAMA moorings presently have air-sea heat, moisture and momentum flux measurement capability. The RAMA plan calls for 8 flux sites when completed. Enhancements to the primary ATLAS measurements in each array provide the functionality for all flux reference moorings to measure shortwave and longwave radiation, precipitation, sea level pressure, water temperature with higher vertical resolution, surface and subsurface salinity at 8 depths, and velocity at one or more depths. PMEL's contributions to OceanSITES are highlighted in a web site created in 2008, <http://www.pmel.noaa.gov/tao/oceansites/>. As part of this website, a heat, moisture, buoyancy and momentum flux data display and delivery page has been created (<http://www.pmel.noaa.gov/tao/disdell/flux/main.html>).

2.4 Tropical Sea Surface Salinity

FY 2008 funding provided support to complete the instrumentation of tropical moorings to measure sea surface salinity (SSS) measurements at all surface mooring sites. The 55th and final site of the TAO array was instrumented in March 2008. Future funding will be required only to maintain TAO sites as a contribution to the combined TAO/TRITON array. Data from this array are supporting efforts to better describe and understand variability and trends in surface salinity. One paper on trends in the western Pacific over the past 30 yrs is under review (Cravatte et al, 2008) and a second on the mean seasonal cycle in the Pacific is in preparation (Bingham, Foltz, McPhaden, and Suga).

3. VANDALISM

New hardware which inhibits the removal of sensors and the buoy towers was introduced on moorings deployed in September 2007. The effectiveness of these efforts has not yet been determined since few moorings with modifications have been recovered. Initial indications are not conclusive. Of two such moorings deployed in the Bay of Bengal, one was recovered in tact, while the other was missing its tower. The latter stopped transmitting in May 2008, coincident with the passage of cyclone Nargis. While the cessation of data telemetry was undoubtedly due to the cyclone, the cause of the loss of the tower has not yet been determined. Buoys on two surface moorings deployed in 2008 were modified to inhibit vandals from climbing aboard and attaching lines to the buoy. Transmissions from both moorings have continued since deployment in August 2008. These moorings do not have any meteorological sensors. If the modifications prove successful in reducing mooring loss, surface sensors protected from removal and damage will be reintroduced to the moorings.

4. CURRENT METER PERFORMANCE

Based on the relatively low data return rates for the Argonaut-MD, PMEL is looking at alternative instruments to replace these instruments. One possibility is a new short-range Doppler current meter recently developed by YSI RDI, Inc. PMEL has worked with the manufacturer on design criteria and testing of prototypes of this instrument. Field testing is underway on PMEL moorings and the DVS performance will be evaluated in 2009. Other point Doppler current meters were deployed in October 2008 on two PIRATA moorings for comparison with ADCPs and the instrument presently used on tropical surface moorings.

5. COMMUNITY SERVICE

McPhaden, the TAO Project Director, is chairman of the Tropical Moored Buoy Implementation Panel and serves on the PIRATA Scientific Steering Committee (SSC), the OceanSITES Science Team, the CLIVAR/GOOS Indian Ocean Panel, the CLIVAR Pacific Panel, the CLIVAR Global Synthesis and Observations (GSOP) Panel, and the JCOMM Observations Coordination Group. He is a member of the UK RAPID-WATCH Program Advisory Group and an editor for the *Bulletin of the American Meteorological Society*. McPhaden also is President-elect of the AGU. In FY 2008, he attended several CLIVAR panel meetings and a PIRATA SSC meeting in Natal, Brazil.

The PMEL TAO Project Manager represents the Tropical Moored Buoy Implementation Panel at the JCOMM Data Buoy Cooperation Panel (DBCP), the International Buoy Programme for the Indian Ocean (IBPIO) and serves on the OceanSITES Data Team. He attended the DBCP meeting in October 2007 (Jeju, Republic of Korea) and OceanSITES meeting in April 2008 (Vienna, Austria). He worked with the Climate Program Office and the International Activities staff in developing IAs for collaboration with India and Indonesia towards the implementation of RAMA. He also helped to lay the groundwork for a long-term collaboration with ASCLME for provision of ship time to implementation of RAMA.

Lumpkin, project collaborator at AOML, is scientific advisor for the Global Drifter Program and serves on the PIRATA SSC alongside McPhaden. He is also a member of the CLIVAR Tropical Atlantic Climate Experiment (TACE) working group on observations. He attended the TACE/AMMA meeting in Karlsruhe, Germany in November 2007 and the PIRATA-13 meeting in Natal, Brazil in February 2008. In December 2007, he co-convened (with Brian King) the CLIVAR/GSOP workshop on velocity observations in La Jolla, CA. He served as OAR representative for the safety inspection of the R/V Ronald H. Brown in Montevideo, Uruguay in April 2008, where he provided input regarding how problems with the vessel were impacting the scientific objectives of various cruises. He helped organize the charter of the R/V Antea for the October 2008 PIRATA Northeast Extension cruise, and developed the cruise plan with PMEL colleagues.

6. PUBLICATIONS (Refereed Literature)

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